International Basic and Applied Research Journal

Journal homepage: https://sites.google.com/site/ijbarmeplrf/

Research Article (Subject –Geophysics)

Aeromagnetic Study of Okitipupa Region, Southwestern Nigeria

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Received:7 June 2016, Revised Received: 4 July 2016, Accepted: 8 July 2016

Abstract

Aeromagnetic technique is used for mapping of inland extension of Chain Fault zones into the south-western part of Nigeria using aeromagnetic data of Okitipupa, Southwestern Nigeria. Aeromagnetic data acquired in the study area was processed to produce various maps and interpret geological features that could be a zone of mineral accumulation as well as to understand subsurface structures for the purpose of subsurface geologic mapping. Analyses involved the application of Upward Continuation, Vertical Derivative and Reduction to pole, total magnetic intensity, analytical signal, 3-D Euler deconvolution and Radial power spectrum. The investigation revealed the nature of magnetic anomalies which shows different rock types having different magnetic intensities. Qualitative and quantitative interpretation of individual magnetic anomaly and geological knowledge of the survey area yielded information on the depth of geological features (e.g. rock contact, faults or fractures), structures and magnetic properties of rock units. From the vertical derivative analyses, the small size mineralized bodies and shallow features in the study area were mapped. On the upward continuation filtered map, a west – east linear feature with a trend similar to the major orientation of the regional faults in shown area was estimated. The rift valleys in the area are long, deep valleys bounded by parallel faults, or fractures. In addition, the predominant SW/NE, SE/NW and E-W trending linear structures mapped as fracture/faults cut the basement and penetrated the overlying Cretaceous and Tertiary sediments in the study area.

Keywords: Aeromagnetic, Derivatives, 3D- Euler, Average radial spectrum, Okitipupa, Nigeria.

Introduction

Aeromagnetic dataset have long been utilized as a fundamental tool for interpreting buried Precambrian Basement rocks and, due to improved acquisition and enhancement techniques, are now being used to study poorly exposed sedimentary successions (Peirce et al., 1998). Analysis of aeromagnetic dataset has been vital to studies investigating crystalline Basement hidden beneath Phanerozoic cover in southwestern Nigeria (Pilkington et al., 2000). These studies have

appreciably advanced models that address the tectonic evolution of the southwestern, Okitipupa ridge, link sedimentary cover of Dahomey sedimentary basin to Precambrian basement in the southwestern Nigeria, and explore genetic relationships between the Precambrian basement and phanerozoic geology of the southwestern Nigeria.

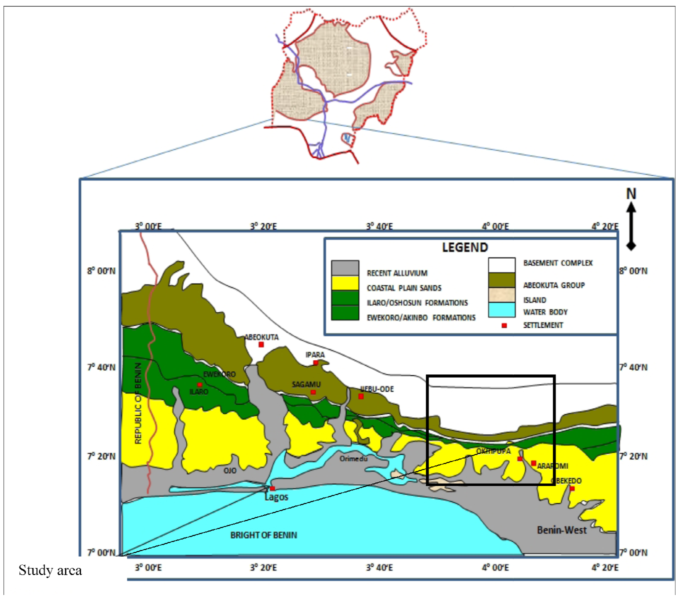

Fig. 1. Geological map of the study area.

The Nigerian Geological Survey Agency collaborated with Fugro to acquire High resolution data over the Precambrian and basement and Sedimentary basins in Nigeria. High resolution magnetic and gravity data are mostly situated in areas of high petroleum interest like the Niger Delta, Dahomey, Anambra, Chad basin zones basins and Gulf of Guinea are typically the property of petroleum companies. The dataset are not always available for academic studies while the primary objective of the government-funded airborne geophysical programme is to provide the industry and the geoscientific community with modern data that are relevant to the exploration for mineral resources and for the general understanding of the geology of Nigeria. Most of the previous surveys have covered onshore areas.

The geometry and structure of Precambrian basement in the region are commonly accepted as major influences of Phanerozoic sedimentological, stratigraphic, and structural patterns that control economic deposits (Cecile et.al., 1997). The study area is located within the Dahomey sedimentary basin of Nigeria and indicators that have been found useful in mineral exploration includes faults, fractures (lineaments), arched, or domed structures in addition to oxidized and hydrothermally altered areas (Peterson et al., 1976), and the application of aeromagnetic methods amplifies the recognition of the difference in depths of magnetic sources, structures like faults, dike, lineaments, and layered magnetic susceptibility given in the unevenness of complexes.

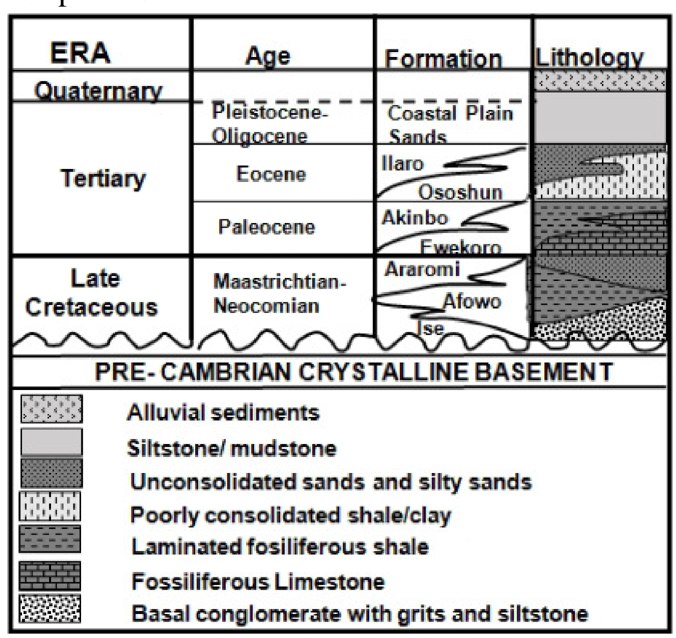

Fig. 2. Stratigraphy and lithologic features of Dahomey Basin (After Omatsola and Adegoke, 1981)

The Dahomey Basin, within which Okitipupa sheet 282 falls, extends from South East Ghana in the West to the Western flank of the Niger Delta. It was formed consequent to the opening of the South

Atlantic probably during the Cenomanian (Adegoke and Omatsola, 1981). There was a rift generated basement subsidence during the lower cretaceous along an RRR triple junction (Hurley and Rand, 1969). This resulted in the deposition of a thick pile of continental grits, limestone and pebbly sands over the entire basin. The area is characterized by sand ridges, lagoon and swampy flats of sedimentary terrain. It consists of alternating sands and shales units. The youngest formation, the Araromi formation is mostly marine shale with thin limestone bands. Oil sands formerly known as tar sands are composed of bitumen, mineral matter which includes clay or sand and water. The bitumen also referred to as heavy oil constitutes an important energy resource that must be rigorously treated in order to convert it to an upgraded crude oil before it can be used in refineries to produce gasoline and other fuels.

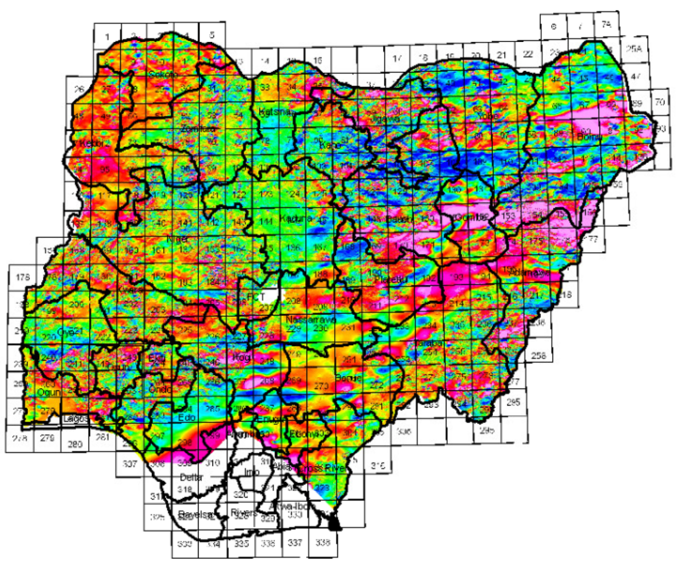

Fig. 3. Nigeria Magnetic Index map (Source: NGSA).

Thus oil sand is economically valuable and important to the community in particular and the nation in general, such as Nigeria, as a source of revenue. It contains about 3000m thickness of sediments which is thickness off shore (Coker and Ejedawe, 1983). The basin is an accurate coastal depression and the on -shore part of it underlies the coastal plains sands of South- Western Nigeria, Benin and Togo. A faulted high, the Okitipupa basement ridge separates the Dahomey basin from Southern Benue Trough.

Interestingly, high resolution aeromagnetic data of the study area, whose interpretation will reveal subtle anomalies, have been acquired by the Nigerian Geological Survey Agency (NGSA). However, the data have not been studied to fill the gap created by the limitations of the previous geophysical studies. As such, the broad aim of this study is to use the high resolution aeromagnetic dataset to provide new insight on the structural architecture of the study area.

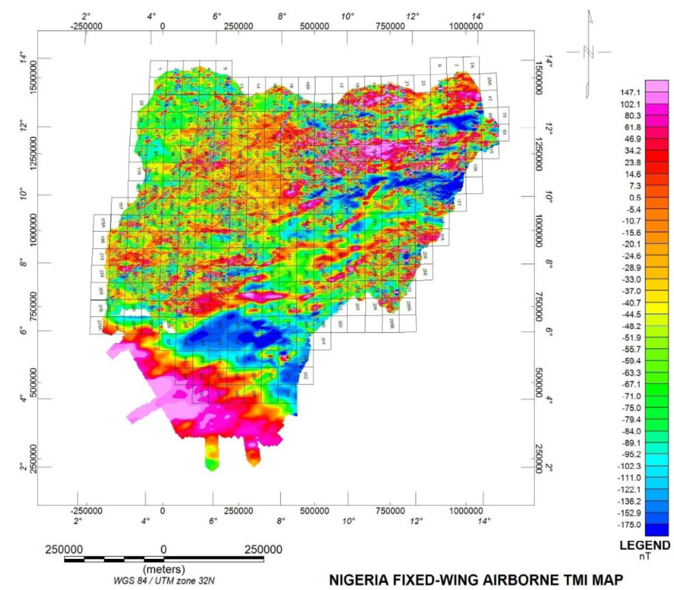

Fig. 4. Nigeria Fixed- wing Airborne TMI Map (Superimposed federal Survey half Degree Sheets) (Source: NGSA).

Location and Geology

The study area lies within latitude 0060381N-0060401N and longitude 0040341E- 0040371E (Figure 1), and falls within the eastern Dahomey Basin. Dahomey Basin is a regional sedimentary basin that extends from Southeastern Ghana (Volta delta) in the west to the western flank of the Niger Delta in the east (Omatsola and Adegoke, 1981a;

Whiteman, 1982), southwestern Nigeria (Fig. 1). The basin is bounded by Ghana Ridge to the west, which is an extension of the Romanche Fracture Zone; and on the east, by the Benin Hinge line, a basement escarpment which separates the Okitipupa Structure from the Niger Delta Basin and also marks the continental extension of the Chain Fracture Zone (Wilson and Williams, 1979). The evolution of the basin is linked to the opening of the Gulf of Guinea during the Early Cretaceous-Late Jurassic (Burke et.al., 1971; Kingston et.al., 1983). It is made up of inland, coastal and offshore sedimentary units (Obaje, 2009). The onshore margin is predominantly clastic sediments directly deposited on the basement complex and the offshore margins are thick, fine grained consisting of Cenozoic sediments (Whiteman, 1982).

Stratigraphically, the oldest sediments in the basin belong to the Abeokuta Group (Omatsola and Adegoke, 1981b) which in turn consists of Ise Formation, Afowo Formation and Araromi Formation (Fig. 2). This group is the thickest sedimentary unit within the basin (Akinmosin et.al., 2012). Ise Formation unconformably overlies the Precambrian Basement Complex of southwestern Nigeria. It is made up of conglomerates, siltstones and grits at the base and overlain by a coarse to medium grained sands with interbeded kaolinite (Nton, et.al., 2009). An age range of Neocomian-Albian is assigned to this formation based on paleontological assemblages. Overlying the Ise Formation is the Afowo Formation; consisting of coarse to medium grained sandstone with shale, silt and claystone interdeds. Based on palynonogical evidence, the formation is assigned Turonian-Maastrichtian age (Billman, 1992). Afowo Formation is successively overlain by Araromi Formation which is made up of shale, siltstone and interbeds of limestone and sandstone. It was dated Maastrichtian to Paleocene based on foramifera contents [Omatsola and Adegoke, 1981]. The Abeokuta Group is overlain by the Imo Group (Ewekoro and Akinbo Formations (Nton and Elueze, 2005), the Ososhun Formation, Ilaro Formation and Coastal plain sands [Jones and Hockey, 1964).Ewekoro Formation is the oldest of the Tertiary sediments which overlies the Araromi Formation. It is made up of fossiliferous, shaley limestone sequence of Paleocene age (Adegoke, 1977).

Overlying the Ewekoro formation is the Akinbo Formation which consists of shale and clay units. The claystones are kaolinitic in nature and have concretions. The base of the formation is defined by glauconitic rock bands with limestone lenses (Ogbe, 1972). It is dated Paleocene-Eocene age (Omatsola and Adegoke, 1981). The Akinbo Formation is succeeded by Ososhun Formation which is made up of greenish-grey clay, black-grey shale and interbedded with sandstones.The shale is thick and laminated and glauconitic. Ososhun is phosphatic and this distinguishes it from the underlying Akinbo Formation. The age of the formation is Eocene (Jones and Hockey, 1964, Ogbe, 1972, Ako et.al.,1980). Ososhun Formation is conformably overlain by Ilaro Formation and it consists of massive, yellowish, poorly sorted, cross bedded sandstone. The formation shows a lateral change in facies. Eocene age is assigned to this formation by (Ogbe, 1972; Omatsola and Adegoke, 1981). The youngest formation in the basin which succeeded the Ilaro Formation is the Benin Formations which is also known as coastal plain sands. It consists of poorly sorted sand with clays occurring as lenses. The sands are occasionally cross bedded are predominantly of estuarine, deltaic and continental in origin [Kogbe, 1989]. The formation is of Oligocene-Recent in age (Ogbe, 1972; Omatsola and Adegoke, 1981).

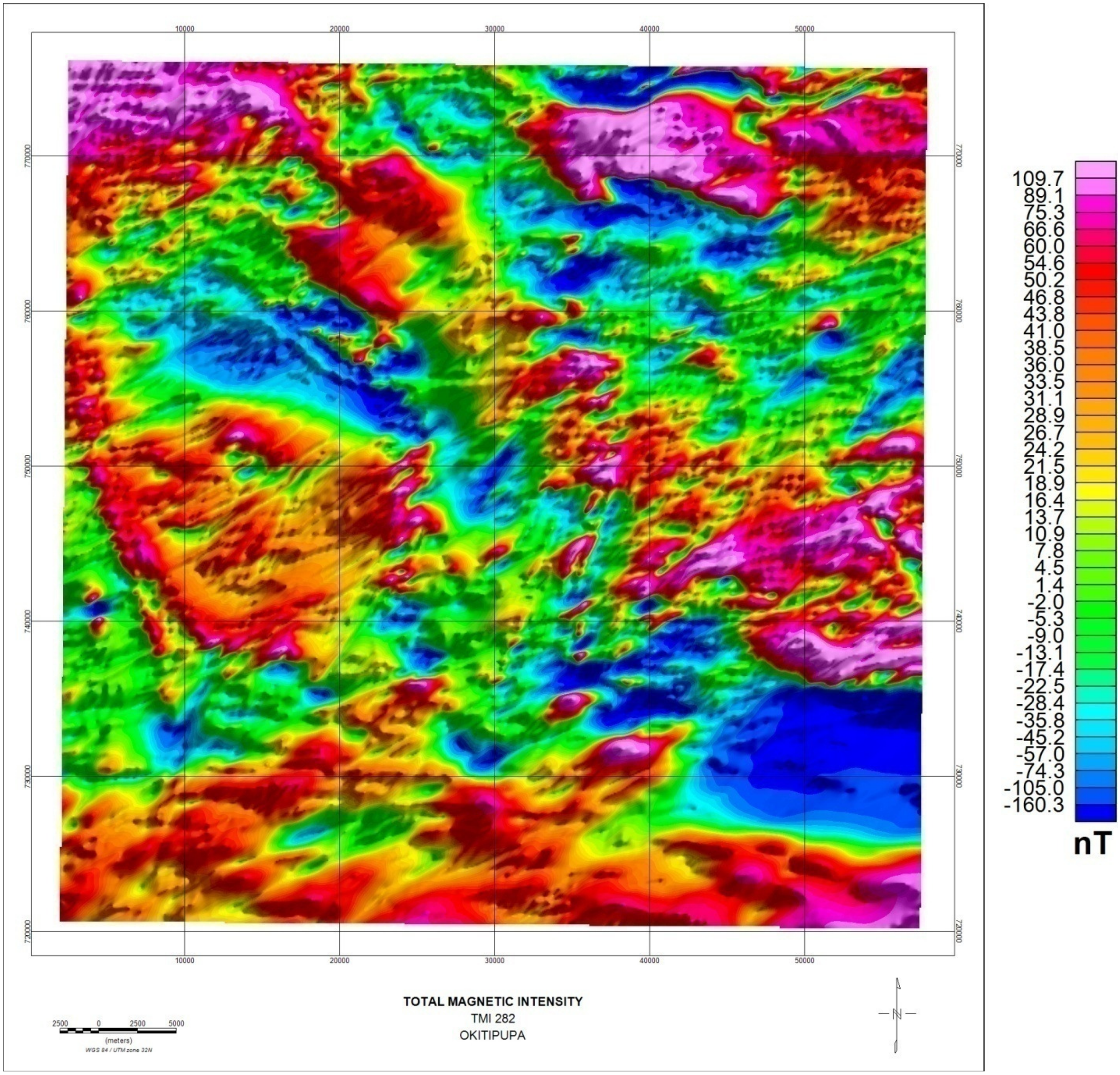

Fig. 5. Color shaded total magnetic intensity map of Okitipupa sheet 282 Southwest

Materials and Methods

Aeromagnetic Data Acquisition

The nationwide mandate of acquisition of high resolution airborne geophysical survey aimed at assisting and promoting mineral exploration in Nigeria, aeromagnetic data was acquired between 2003 and 2009 by Fugro Airborne Survey Limited for the Nigerian Geological Survey Agency (NGSA) (MMSD, 2010). The data was acquired systematically by dividing the country into geological blocks with divergent measurement parameters for each block with the eventual production of an aeromagnetic map for the whole country (Fig. 3 and 4).

The following equipment specifications were used- Scintrex CS3 Cesium Vapor magnetometer, Data Acquisition System FASDAS, Magnetic Counter

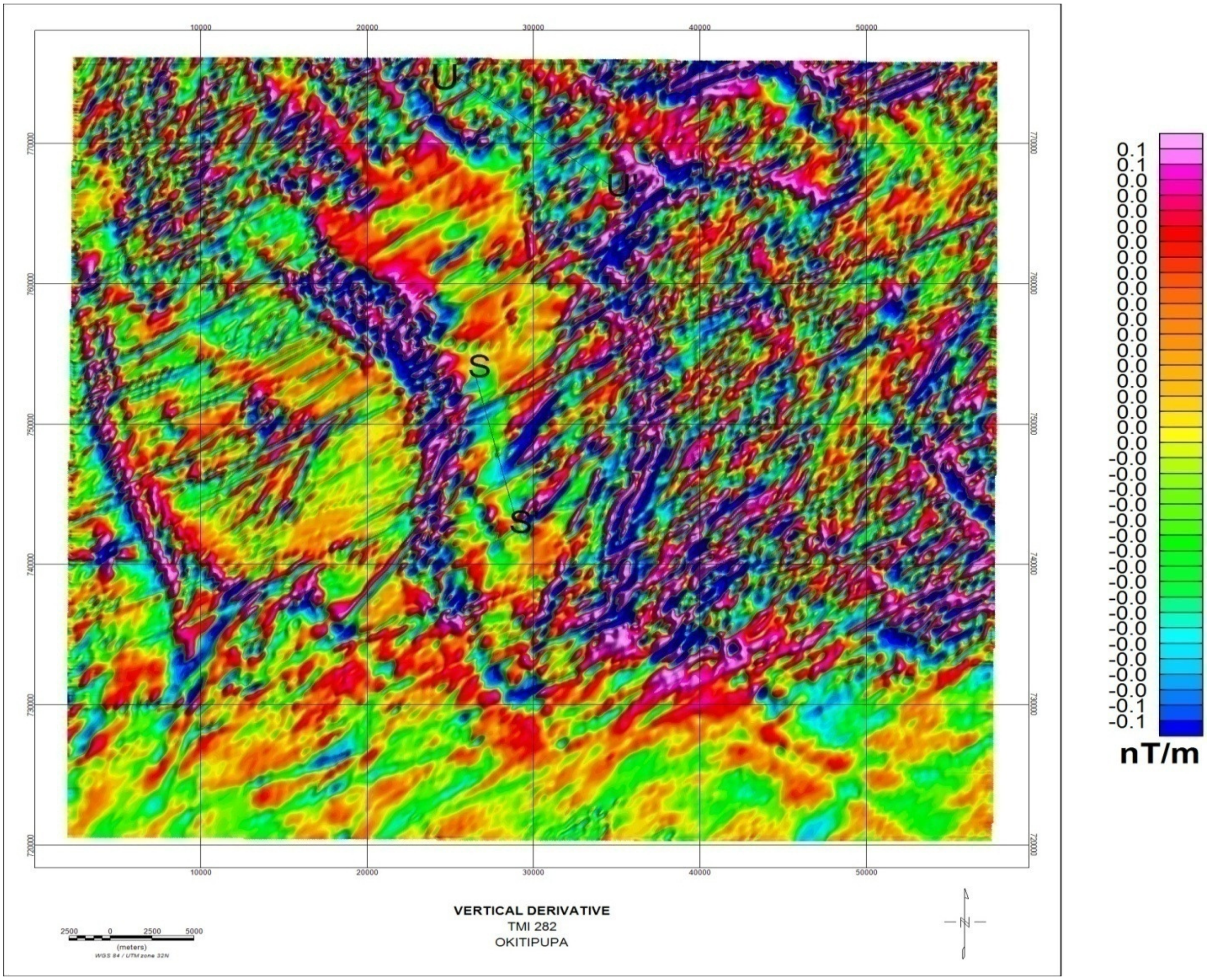

Fig. 6. The vertical derivative map of the study area.

FASDAS, Radar Altimeter KING KR405/KING KR405B, Barometric Altimeter ENVIRO BARO/DIGIQUARTZ. Scintrex CS3 optically pumped Cesium Vapor magnetometer was used for scalar measurement of the Earth's magnetic field. It can be used in a variety of applications such as airborne, satellite, ground magnetometry, or gradiometry. It is highly sensitive and measures in the range of pT (1 pT = 0.001 nT) in a measuring bandwidth of 1 Hz and this sensitivity does not deteriorate as the measured ambient field decreases. It measures between 15,000 nT and 100,000 nT. The sensor head has an electrode-less discharge lamp (containing cesium vapor) and absorption cell. Electrical heaters bring the lamp and the cell to optimum operating temperatures with control and driving circuits located in the electronics console. Heating currents are supplied to the sensor head through the interconnecting cable.

The area under study, Okitipupa Southwest and its environs designated as Sheet 282; is part of Block B and was surveyed in Phase 1 of the project. The survey was carried out by fixed wing (Cessna) caravan -208B ZS-FSA, 208 ZS-MSJ,406 ZS-SSC aircrafts covering a total of 235,000 line kilometers

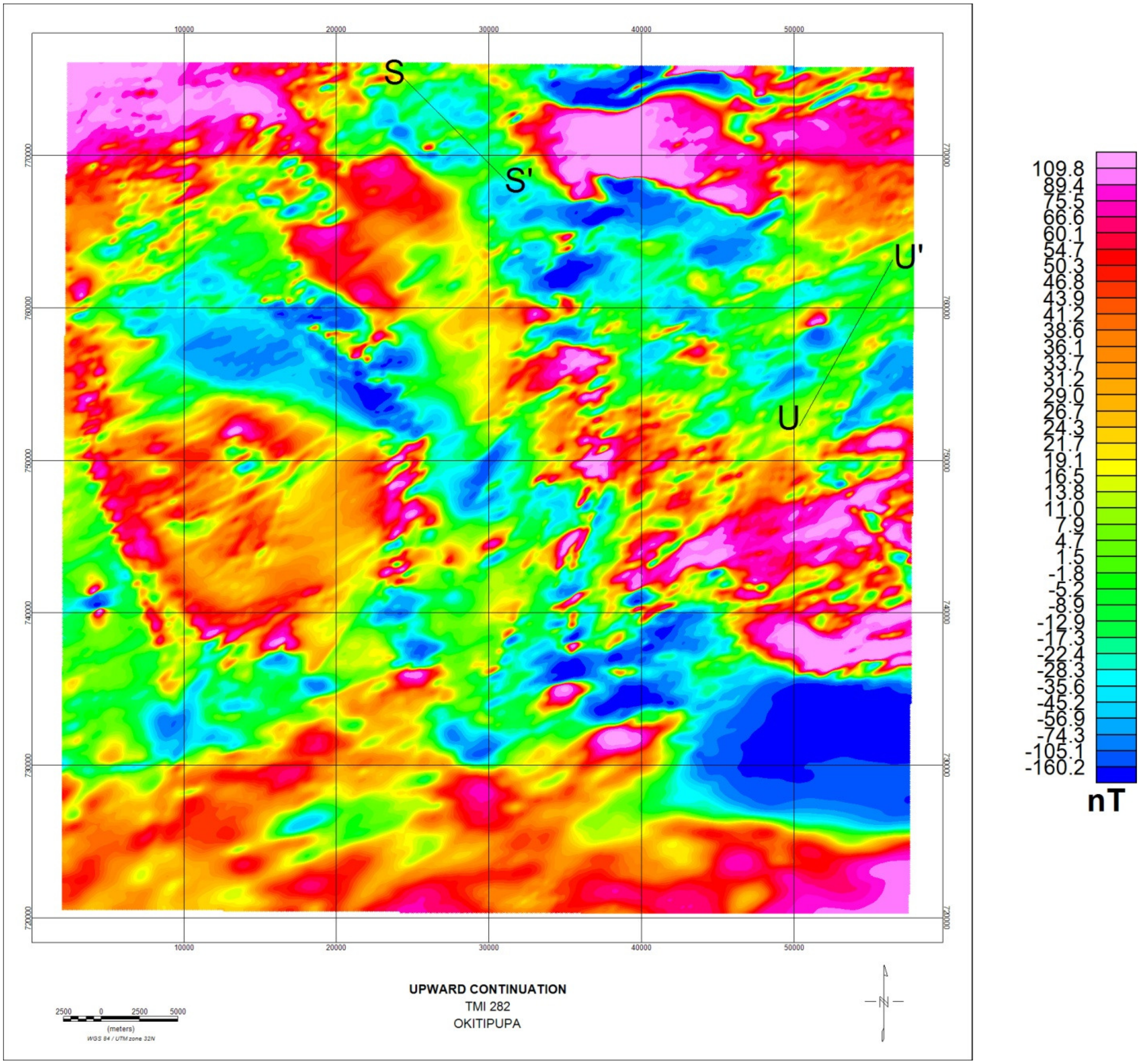

Fig. 7. The upward continuation map of the study area.

with a flight spacing of 200 meters and a terrain clearance of 80 meters, The flight direction was NW-SE with tie-line spacing of 200 meters and tie-line direction of NE-SW.

A recording interval of 0.1 secs and a grid mesh size of 50 meters were applied in the World Geodetic System of 1984 (WGS84) within UTM Zone 36S,central median 33^{o}C East, Central scaling factor 0.999 6and with the Spheroid Clark 1880/Arc 1960 coordinate system.

Data Processing

The data is that of total field and is in a gridded form as a total magnetic intensity (TMI) map (Fig. 5). This method fits minimum curvature curves (which is the smoothest possible surface that would fit the given data values) to data point using method described by Briggs (1974).

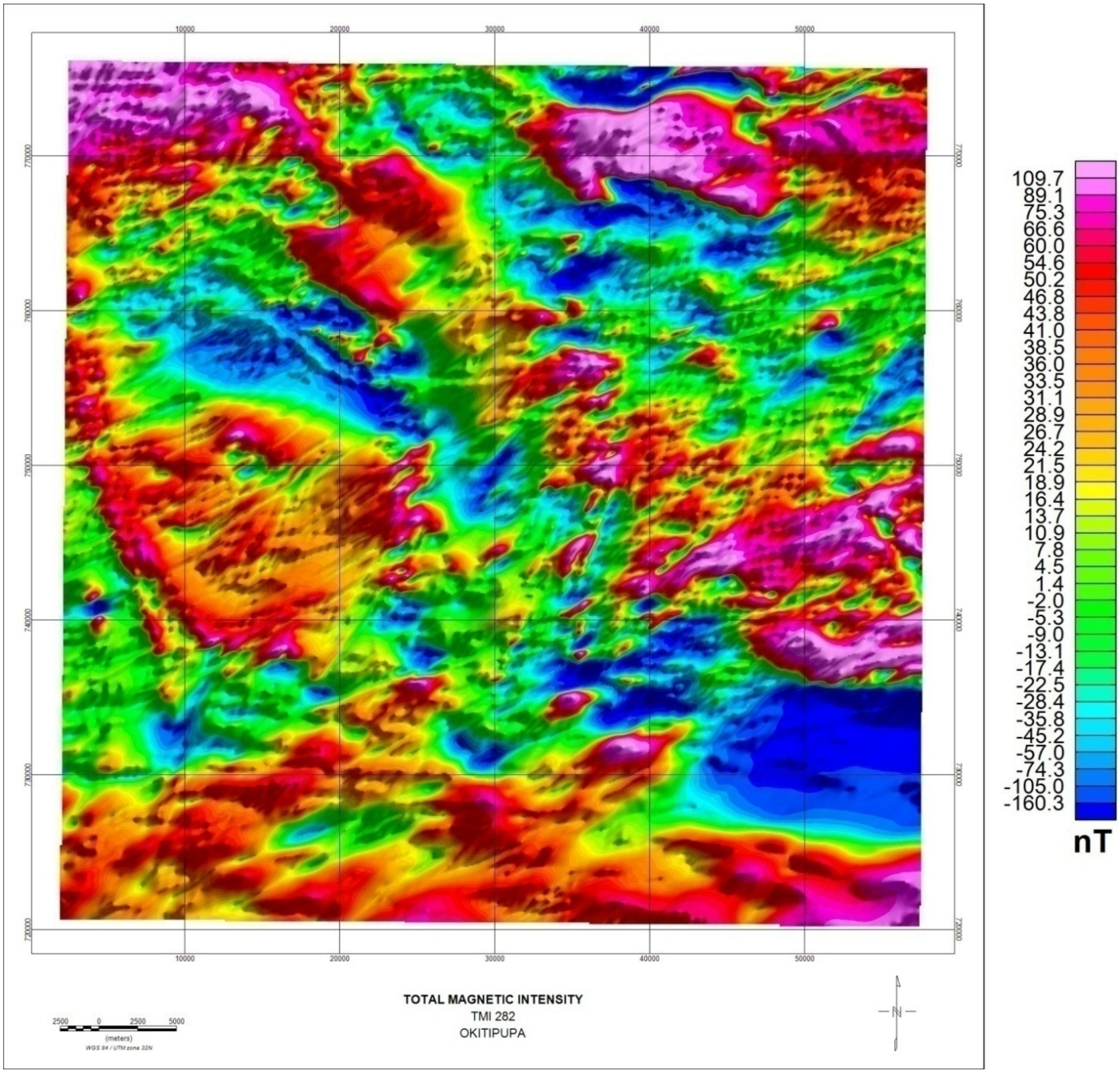

Fig. 8. The total magnetic intensity map (TMI) of the study area.

Butterworth filter (low-pass filter) was applied in accordance with I.G.R.F reduction technique. A low-pass filter is a filter that passes low-frequency signals and attenuates (reduces the amplitude of) signals with frequencies higher than the cut off frequency. The actual amount of attenuation for each frequency varies depending on specific filter design. Low-pass Butterworth filter was applied to the total magnetic intensity data to remove regional effects. An ideal low-pass filter completely eliminates all frequencies above the cut off frequency.

$$D = kH/\gamma \qquad 1$$

Where D is the density contrast, k is magnetic susceptibility, H is the total magnetic field intensity, and γ is the universal gravitational constant. This relationship assumes that the magnetization is induced and no remanence is present as seen in equation 1.

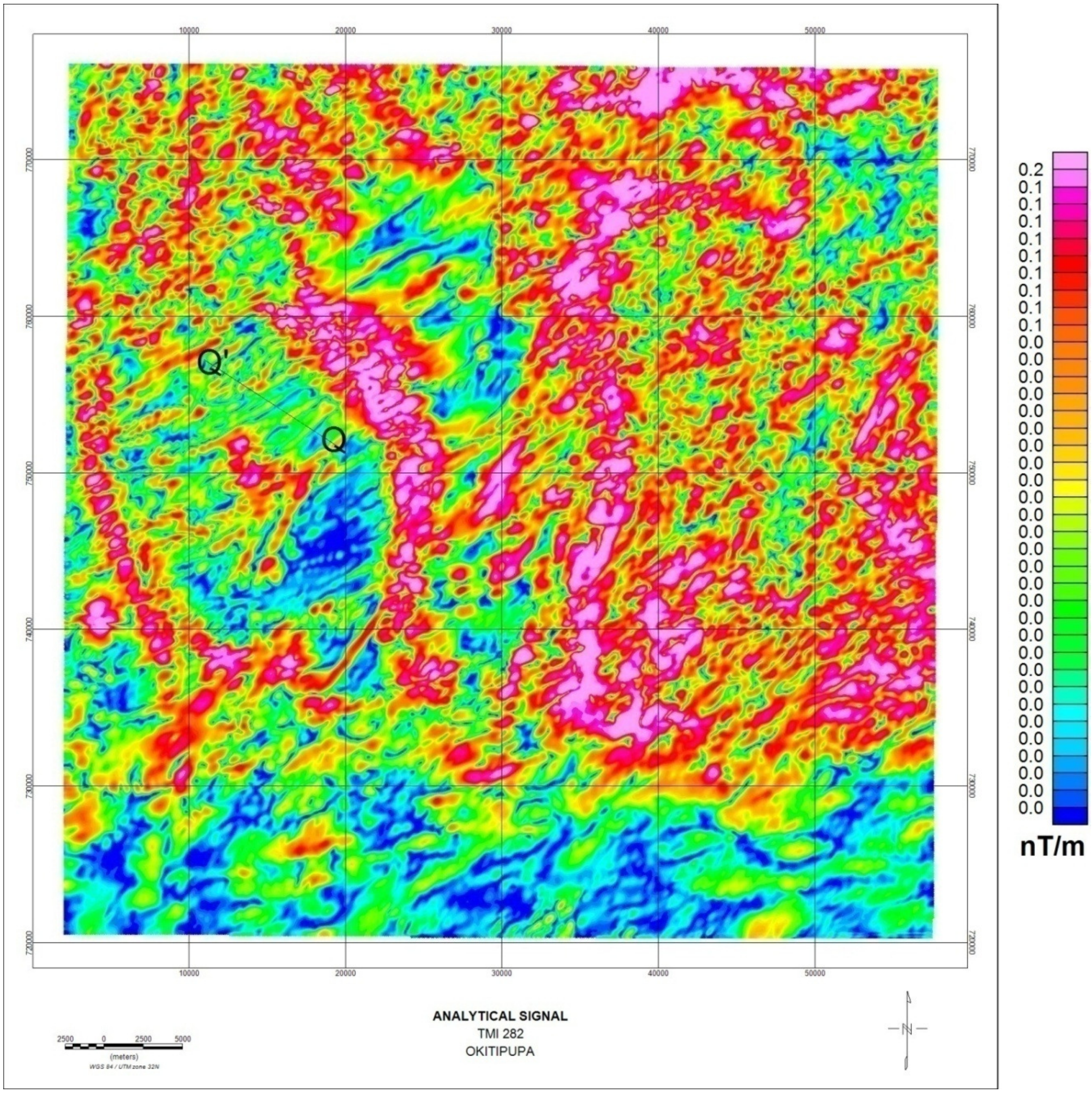

Fig. 9. The Analytical Signal Map of the Study area.

Upward Continuation, Vertical Derivative, and Reduction to pole, total magnetic intensity, analytical signal, 3-D Euler deconvolution, radial power spectrum were determined using Oasis MontajTM.

In this study, the Euler deconvolution algorithm using Oasis MontajTM for location and depth determination of causative anomalous bodies from gridded aeromagnetic data was used. The map thus produced shows the locations and the corresponding depth estimation of geologic sources. Also, Extended Euler deconvolution was carried out to determine the depth to the magnetic basement from profiles at estimated level of certainty Reid et al., 1990. Table 1 shows the summary of the structural indices for simple models in magnetic field where the following structural Index (ŋ) values 1.0 and 2.0 were used based on the geological models of the source to be individual dikes, sills, and horizontal cylinder as in the case of large plutons respectively

(Osinowo and Olayinka, 2013; El Dawi et al., 2004).

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Table 1. Summary of the structural indices for simple models in magnetic field.

Structural index, n	Types of magnetic model	Characteristics
0.0	Contact with large extent	Circles are intertwined with no particular pattern
0.5	Contact with small extent	Circles are intertwined in a pattern that is linear and in rows
1.0	Sills and dyke, thin prism with large circles	Circles are intertwined in a straight line
2.0	Vertical and horizontal cylinder	Occurs like a vertical pipe and Circles intertwined neatly with regular circumference
3.0	sphere	Occur has sphere bodies of circles with a common axis connecting them.

Results and Discussion

According to Dobrin and Savit (1988), the main use of any aeromagnetic and their derivative maps in mineral prospecting is to make geological deduction from them. And from the range of magnetic intensity values of these data, information on subsurface lithology, trend and geological structures can be obtained.

Fig. 4 gives the shaded colour aeromagnetic map of the study area and the amplitude ranges from -160.3nT to 109.7nT suggesting contrasting mineral types in the basement of the study area. From the maps, it showed that the study area is divided into 2 parts. Areas with low magnetic values (where magnetic intensities are lower than 70nT) and areas with high magnetic values (where magnetic intensities are higher than 70nT).In low latitude magnetic region specifically around the equator of which Nigeria is situated, a low / negative magnetic peak values represent typical anomalous signatures (Parasnis, 1986; Fieberg, 2002). Low magnetic intensities dominated the southwestern region and part of the Northern region of the study area while high magnetic intensities dominated the Eastern, Northwestern and part of the Southern region of the study area. Areas with high magnetic intensities are suspected to be due to near surface magnetic minerals such as tar sand rocks (sedimentary or metamorphic) with a suspect outcrop like sedimentary or metamorphic marked on the maps, while the magnetic lows are suspected to be due to the presence of non-magnetic minerals such as fault, fracture, crack or contact between two rocks.

The Vertical Derivative Map of the Study Area

Figure 6 gives the second vertical derivative filter that was applied to the aeromagnetic data to enhance local anomalies blocked by broader regional trends. The second vertical derivative map helps to highlight details and breaks in anomaly texture of near surface minerals i.e. subtle, local and short-wavelength anomalies are emphasized. The short-wavelength anomalies marked S and U on this map are product of near surface small sized mineralized bodies and or geological features. The reason these anomalies are not seen in the original aeromagnetic map is because they have been obscured by stronger effect of wider regional features in the area. The north-south trending elongated low magnetic intensity anomaly marked (U – U') at the north-eastern edge of the map is identified as a fault zone. As seen in (Fig. 6), it is discovered that the concentration of the mineral is seen to trend from southwestern part to north eastern edge of the map, while there is low or less concentration of the mineral spreading below the

map from southwestern part to the southeastern part of the vertical derivative map of the study area. The peak of magnetic susceptibility is shown on the legend is between 0.1nT to 0.1nT which is pink in colour, the intermediate or transition zone is the green to red colour portion of the legend which is between -0.0 to 0.0nT and the area with the lowest susceptibility is within the range of –0.0nT to -0.1nT which is the region with blue colour.

The Upward Continuation Map of the Study Area

Figure 7 gives upward continuation colour shaded relief map of Okitipupa deduced from the aeromagnetic data of the area. The TMI must be upward continued to bring out the structural character of the subsurface. The anomaly patterns identified in this map are a qualitative representation of spatial variation in the magnetic properties of deep basement minerals and structures in the area. Also the elongated low magnetic intensity anomaly marked (S – S' and U-U') is identified as a possible fault zone. This fault defines the principal orientation of the tectonic activities in the study area as it relates with that of the regional faults in this area. Therefore, this map is better used for studying geologic features related to regional factor in the area. The residual aeromagnetic anomalies appear to be sufficiently isolated from regional field. At some places on the residual map there are anomalies that are not present on the total magnetic map. These anomalies are due to magnetic source of shallow source. Local positive residual anomalies observed in parts of the study area are interpreted or suspected to be some outcrops of cretaceous rocks and perhaps concentrations of sand stones within the study area. These could also be associated with ore materials. Negative anomalies are associated with greater thickness of cretaceous rocks contained within the fault-bounded edges and depicting isolated structures and these are well distributed across the study area. The edge of the northwestern side of the map has high susceptibility which shows a peak of magnetic, a bit down the northeastern part of the map shows a translational movement of high magnetic intensity. The central part cutting through all coordinate of the map shows an area of low magnetic intensity and the stretch at the bottom of from southwestern to southeastern part of the map. The highest intensity range is between 89.4nT to 109.8nT and the transition zone is between -22.4nT to 75.5nT with green to brown colour and the lowest zone of magnetic intensity with blue colour.

The Total Magnetic Intensity Map (TMI) of the Study Area

The total magnetic intensity map (Fig. 8) map usually gives lineation as magnetic contours and accentuates the regional geology of the study area useful in mapping structural trends Dobrin and Savit (1988). The analysis of the map shows the general magnetic susceptibility of basement rocks and the inherent variation in the basement complex area under study. The map is presented as colour map for easy interpretation. The coloured maps aided the visibility of a wide range of anomalies in the magnetic maps and the ranges of their intensities were also shown. Areas of strong positive anomalies likely indicate a higher concentration of magnetically susceptible minerals (principally magnetite). Similarly, areas with broad magnetic lows are likely areas of low magnetic concentration, and therefore lower susceptibility.

The magnetic anomaly of magnitude between -160.3nT and -57.0nT appears as the lowest point with relatively low magnetic intensity (deep blue colour). It is observed in the central, northern, southeastern, south and little traces in the northwestern and southwestern parts of the study

area. Closely followed by these in magnetic intensity values are anomalies with values ranging between -42.2nT and -2.0nT in magnitude (light blue to green colour). These are only prominent at the Northeastern, southeastern parts, and Northern regions with traces of it in the central and Southern and western part of the study area. More so, notable anomalies followed by these are the anomalies ranging between 1.4nT and 24.2nT (green to yellow colour) noticed in a dispersed form in the study area, and anomalies of magnetic intensity value ranging between 26.7nT and 60.0nT (brown colour) noticed in the Northeastern, southeastern, central parts and little traces in the North and Southern parts of the study Area. Found in reasonable quantities are anomalies of very high magnetic intensity ranging between 66.6nT and 109.7nT (pink colour) which are observed in the Northwestern, South, Central parts of the Study Area. Negative anomalies are associated with greater thickness of cretaceous rocks contained within the fault-bounded edges and isolated structures and these are well distributed across the study area. Summarily, the 2D TMI map of Okitipupa shows that the area is magnetically heterogeneous. Areas of very strong magnetic values (66.6nT to 109.7nT) may likely contain a mineral which brings about the major anomalies (Sunmonu et al., 2014). The areas between -115.1nT to -33.9nT are suspected to contain near surface magnetic minerals like sandstones, near-surface river channels and other near-surface intrusives. More so, well defined boundaries between zones having significant different degrees of aeromagnetic relief often signify the presence of major basement faults and fractures.

The Analytical Signal of the Study Area

The analytic signal profiling (Fig. 9) shapes are used to determine the depth to the magnetic sources and highlights discontinuities and anomaly texture. The Magnitude / amplitude of the peak of the analytic signal signatures are believed to be proportional to the magnetization and that their maxima occur directly over faults and contacts. The 2-D profile analysis of the aeromagnetic data along the transverses suggests that the study area is composed of magnetic minerals in varying quantities along each profile as shown by the series of highs and lows. Major faults may also be recognized by pronounced lows on magnetic profiles. Sharp peaks are indicators of outcrops while broad peaks indicate deep seated or magnetic minerals of very large areal extent. Depth estimates to tops of anomalous magnetic bodies are also generated from analytic signal method. To determine the depths to magnetic sources observed on 2D profiling curves, the anomaly width (model) at half the amplitude was used to derive the depths. The amplitude of the peak of the profiles is proportional to the magnetization. Regional magnetic observation in the study area facilitate the understanding the structural and geological factors that give rise to anomalies; due to the presence of sandstones, bitumen, shales, tar sand, intrusive and other near-surface magnetic minerals.

This map shows that majority of the area mapped has high magnetic intensity with the area show much of pink colour which suggest high intensity as shown in the legend of the map, this stretch through the major part of the northwestern to northeastern and down the southern part of the map through the east and west gives lowest magnetic intensity. The analytical signal map displays the magnetic zone with high intensity of 0.1 to 0.2nT (pink) from north to south and towards the west while low intensity as 0.0 (blue) is visible in the south, southwest and center. The analytical signal ranges from 0.0 nT to 0.2nT.

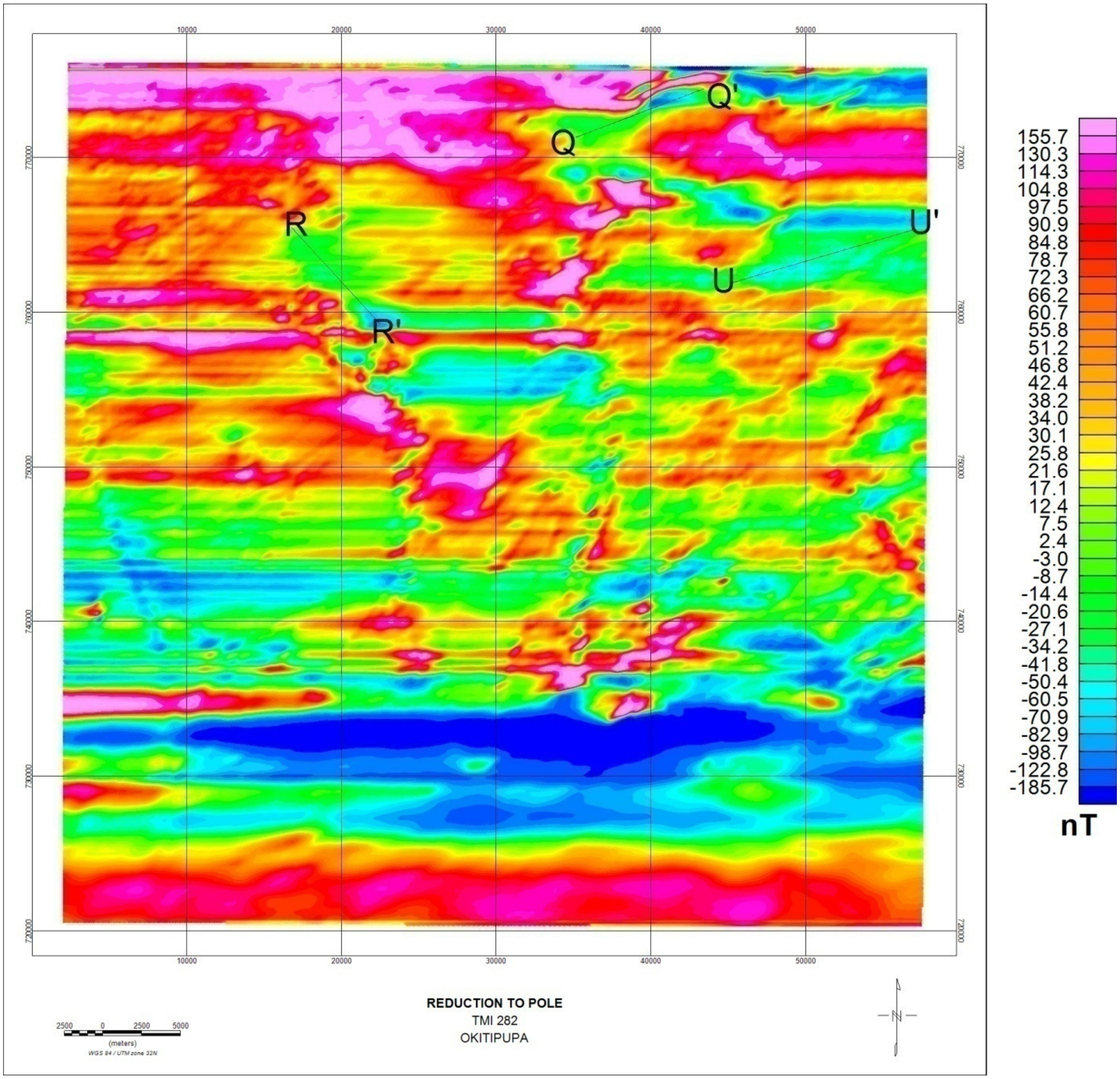

Fig. 10. The Reduction to Pole Map (RTP) of the Study Area.

The Reduction to Pole Map of the Study Area

The RTP magnetic anomaly map (Fig. 10) gives both low and high magnetic frequencies representing points of low and high magnetic signatures respectively in the area. Both TMI (Fig. 8) and the reduction to the pole RTP image (Fig. 10) display similar magnetic features, but in the RTP image the highs (pink colour) of the TMI are seen as lows (blue colour). The RTP map shows more significant features such as structures and lithology in the magnetic signature than the residual magnetic intensity map. At the centre zone, some features observed in the RMI are now seen as linear features trending in the south-north direction. Moreover, other features (e.g. the low magnetic and high magnetic material which is not clearly seen in the RMI image (Fig. 10) is seen in the RTP. Another clear example is the linear magnetic

intensity at the centre of the area. Also observed are some high (pink) features in the RMI image remained high (pink) in the RTP image. Example is the magnetic found at the western part of the area. The RTP image displays the highest magnetic intensity at the western part of the area with the average peak to peak at about -185.7nT. These high magnetic anomalies are seen to trend in the south-north direction. Clear lithological boundaries are also observed in the image. These boundaries are observed from the sharp contrast in the magnetic signature on adjacent magnetic bodies. The high frequency magnetic anomaly at the western part of the area was interpreted as the mineral rich (Blay, 2003).

3D EULER Solution of the Study Area

The Euler deconvolution is an interpretation tool in potential field for locating anomalous sources and the determination of their depths. The Euler deconvolution of the analytical signal of the magnetic field data over the mineral deposit has served as a recent improvement over techniques such as Peters' method (half slope) because the result from its interpretation has enabled a rapid determination of the locations and depths of the mineralization and other geologic sources in the area without prior knowledge of the source geometry and magnetization direction. The method has provided insights into the deposit's mineral geometry and structural setting. And the estimated source depths and geometries provided by the Euler deconvolution method can effectively serve as approximation for the construction of magnetic models of mineral bodies in the studied area. Patterns of deposition and the estimated depths determined from the spectral analysis of the aeromagnetic data of the study area gives complete and full insight to the various magnetic intensity records of the different areas.

Euler 3-D deconvolution produced has shown a very distinct distribution of availability and closeness between the high magnetic intensity and low magnetic intensity. As observed the minerals are in clusters as it is shown in colours ranging from pink, red, yellow, green and blue.

Structurally, the sedimentary rocks of the study area consists of sets of closely related geologic features at the northern, central and southern zones (Fig. 11) and made up mainly of minerals that trend in a northeast to southwest direction while the iron ore bodies in these gneisses are thick and strike northeast – southwest.

The technique was applied to the upward continued aeromagnetic anomaly data to determine depth of magnetic ore bodies and folds in the study area. Structural index 2, which represents cylindrical shaped body, was chosen because magnetic field can be inferred with the body (Dutra and Marangoni, 2009; Dutra, et.al. 2011). This index was ran with window lengths of 10, 15 and 20 and a combination of 20 × 20 window size with the index was used for the interpretation because it gave the tightest cluster of solutions that fitted the expected geological structure Reid et.al., 1990)]. The result is displayed in Figure 11. The results of the Euler solutions indicate that the depth of the magnetic structures range from 1250 to 2000m For the inferred unexposed ring complex, the depth range from Okitipupa ridge outcrop to 1200 m. Typical Euler solutions for structural indexes of 1,2 and 3 are shown in Fig. 11. These show series of SE-NW, E-W and S-N trending anomaly peaks orientation, which conform to the inferred general geologic trend in the study area. Summary of the structural index results of the Euler inversion of the aeromagnetic data based on respective geologic models is presented in Tables 1.

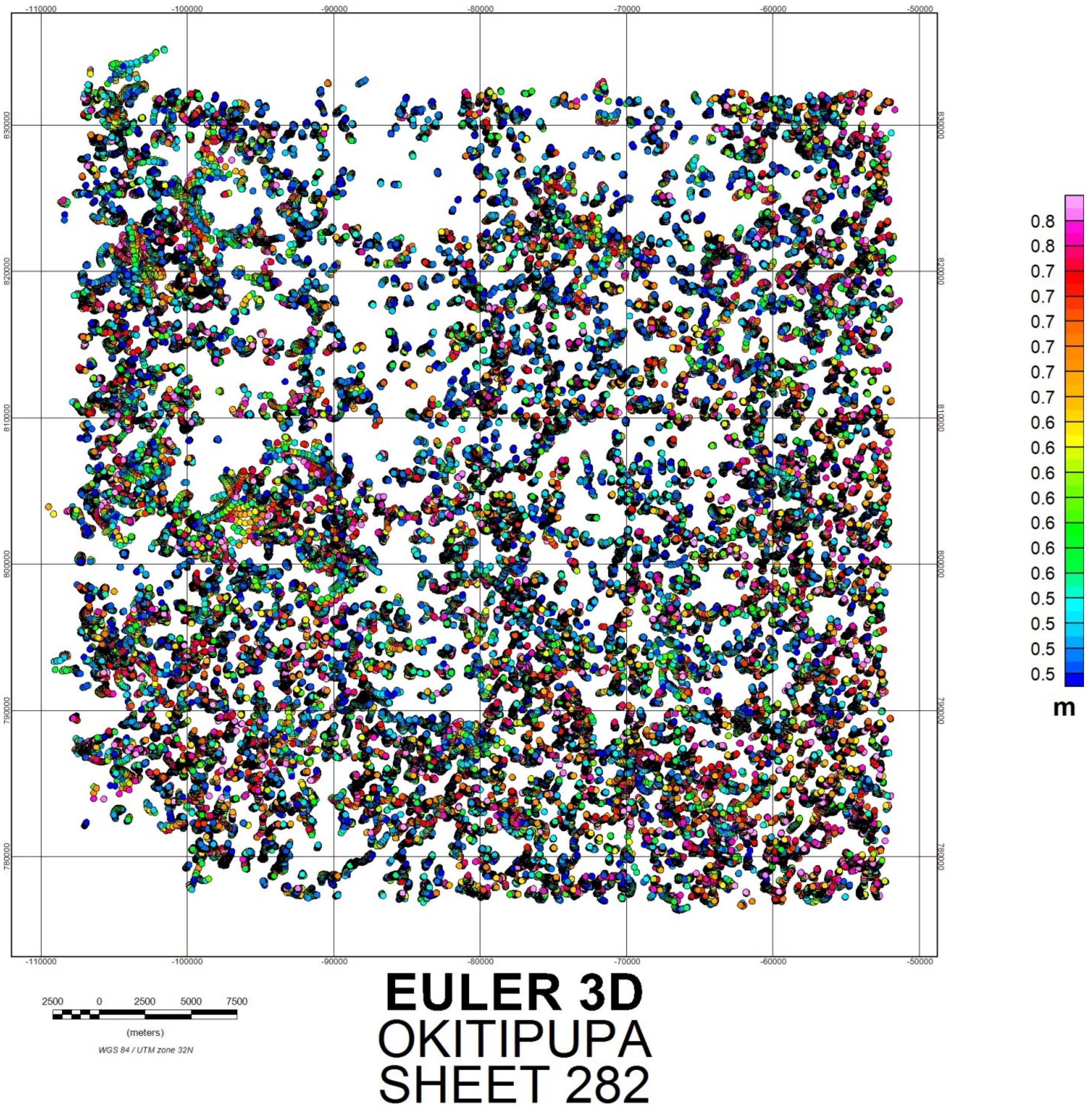

Fig. 11. 3D Euler Map of the Study Area.

3D Map of the Study Area

The 3D contour maps (after subjecting it to drift and diurnal corrections) show the magnetic field intensity on each profile. The 3D magnetic map or inversion has been generated to show the distribution, location and depth of mineral rocks in the study area. The distribution of magnetic highs and lows (i.e. positive and negative anomalies) are as shown by the peaks and the depressions in the surface map of the residual map of Okitipupa (Fig. 12). From the map, it showed that the study area is divided into 2 parts, Areas with low magnetic intensity and areas with high magnetic intensity. Low magnetic intensities dominated the Southwestern, Southern and part of the

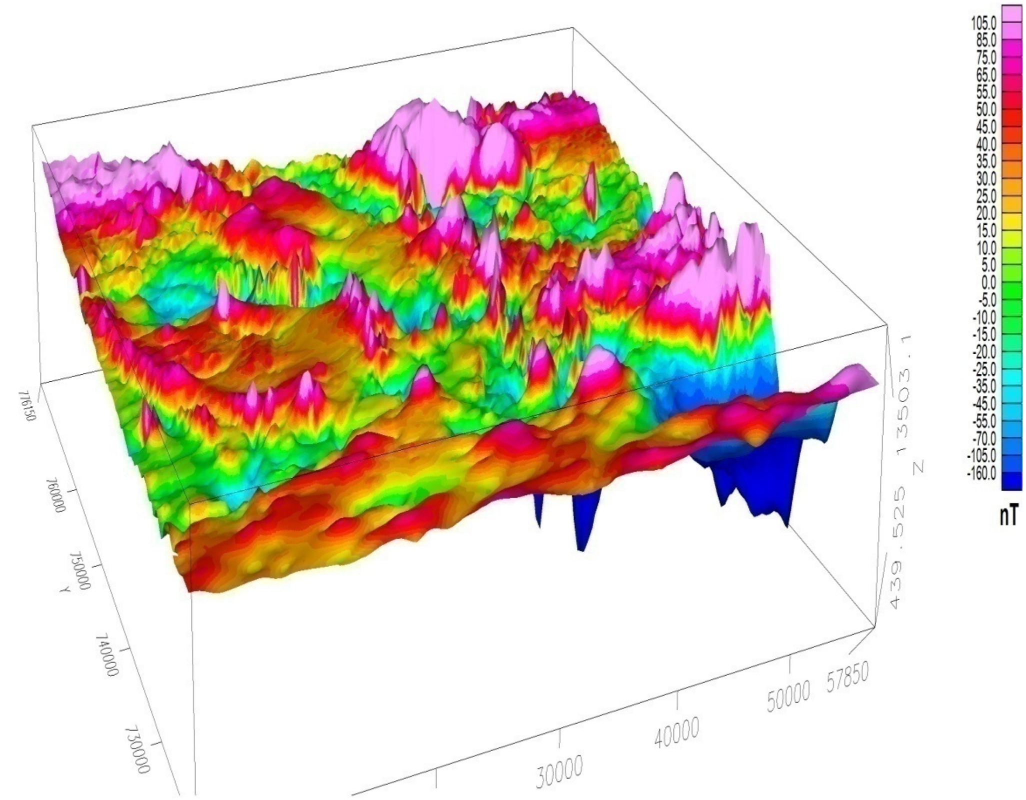

Fig. 12. The 3D Total Magnetic Map of the Study Area.

Southeastern region of the study area while high magnetic intensities dominated the Central, Western, Northwestern, Northern, Northeastern and Eastern region of the study area (Fig. 12). Areas with high magnetic intensities area the competent areas for engineering purposes while areas with low magnetic intensities are the suspected areas for hydrogeologic purposes (Sunmonu et al, 2012). From Fig 12, it further shows that the Southwestern and Southern, Northwestern region of the study area are the promising areas for hydrogeologic prospect because of low magnetic intensities.

The interpreted okitipupa ridge in the eastern part of the study has been recognized to form alignment with the deep sea transform/fracture zone system recognized as Chain transform/fracture zone (Fig. 12). The walls of the inland extension of the underlying ridges coincide with the inferred onshore projection of the two major extensions of Chain transform faults. These fracture zones appear to play major roles in the deformation and rifting of the sheared south-western Nigeria basin margins. The transform fracture zone is responsible for the strike-slip deformations resulting into the graben-horst patterns which influence deposition of sediments from major rivers draining the area from the north to the southern basin margins. Series of the normal/strike-slip faults form major boundaries between the Dahomey basin to the left from the

adjacent Benin basin, and the boundary between Dahomey and Niger delta Basin.

The Radial Power Spectrum of the Study Area

The depths to the top of geologic sources that produced the observed anomalies in the aeromagnetic map were determined using spectral analysis. The radially average power spectrum (Fig. 13) of the Okitipupa aeromagnetic data shows a normal plot that has straight line segments which decreases in slope with increasing frequency. Deep seated and or magnetic minerals of large areal extent are observed along profiles. These could also be associated with deep faults, deep seated volcanic rock or igneous rock. The very sharp anomaly peaks observed along profiles could be attributed to the outcrops of crystalline igneous and/or metamorphic rock or even exposed volcanic rocks. Other anomalies observed as revealed on the profiling are probably due to the presence of near-surface magnetic minerals.

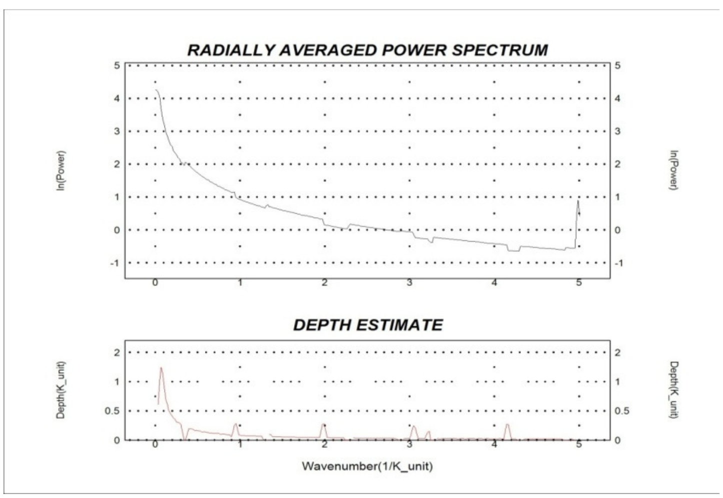

Fig. 13. The Radial Power Spectrum Of The Study Area.

General Depth Estimation from the Quantitative Interpretation

The depths for each anomaly on each profile were calculated and averaged to obtain a representative depth estimate for the profile in the study area. The depth to the magnetic source(s) along the profiles in the study area was found to range between 0.75km to 6.25km, with an average depth of 2.398km for the entire study area which are in agreement with the results of similar previous works in and around the study area.

The depth contour map (Fig.13) showed that the depth is increasing towards the Western part of the signal map and decreases westward. Deep source magnetic anomalies observed at the Western part of the study area ranges from 0km to 0.5km. These regions are recommended for further investigation especially for its geothermal energy potentials. The intermediate depths correspond generally to the top of intrusive masses occurring within the basement. A depth of this magnitude should also be investigated for possible hydrocarbon deposit, and these zones are observed in locations of the study area, the west, southeast, and east-central parts. Depths between 2km to 3.5km (green) represent depths for the true basement surface. It appears to be the dominant depths in terms of spread in the study area, covering the entire northeast, southeast and east. These depths indicate clearly the magnitude of variations in depth of both the basement topography and other intrusive in the area. These areas could also be investigated further for the major magnetic minerals like tar sand, sandstones, bitumen, clay, shale and so on. Additionally, the zone appears to be the store house for the concealed magnetic minerals.

Conclusions

Aeromagnetic method is a useful tool in investigating and determining the location of magnetic minerals and geological features in the study areas. The aeromagnetic data were acquired, processed and enhanced with a view of mapping the lithology units and structural architecture of the study area. The following filter assisted in defining the lithological units/boundaries and intersection of geological boundaries: residual magnetic intensity (RMI), reduction to pole (RTP), analytical signal, upward continuation and vertical derivative. The aeromagnetic intensity anomaly map of Okitipupa (sheet 282) acquired from Nigeria geological survey agency and the 3D magnetic map has been shown. The 3-D magnetic intensity map was generated to show the distribution, location and depth of mineral in the study area. The geophysical and geological interpretation revealed the earth's materials with high magnetic susceptibility at the east towards the northern of the gridded map of the study area, and earth's materials with low magnetic susceptibility at the central toward the south eastern part of the study area, mineral bodies and five fault were delineated and grouped into (NE- SW and NW-SE) trends.

The analytic signal technique showed the magnetization levels of various concealed magnetic bodies, their source locations, their estimated depths and other complex geological structures. Analytic signal technique also allows a rapid evaluation without any assumption as to the geometry or magnetization of the structures. The results obtained from both profiling curves and depth contour map showed that the study area is magnetically heterogeneous and the basement is segmented by faults. The 3D magnetic susceptibility model or inversion generated show the distribution, location and depth of mineral rocks in the study area. Euler deconvolution and Power spectrum is both a boundary finder and a depth estimator. Euler deconvolution extracts information from a grid and the magnetic structures range from 1250 to 2000m. Preliminary interpretation revealed the existence of some structural features such as a likely fault, fracture and contacts between rocks that might contain magnetic minerals. The power spectrum produced shallow depth range of 360 m to 1350 m while the Euler deconvolution which was associated with dikes on the other hand produced deeper depth range of 100 m to 2200 m and this dike structural index best fits the study area. This is because dikes anomaly generally occurs at great depth.

The aeromagnetic method helped in delineating the geological boundaries and structure which controlled the mineralization in Dahomey basin.

Acknowledgement

The authors sincerely thank the reviewers for their constructive comments and suggestions which led to a much improved paper.

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Cite this article: Okpoli, C.C. and Eyitoyo, F.B. 20016. Aeromagnetic study of Okitipupa region, Southwestern Nigeria. International Basic and Applied Research Journal, volume 2, issue no. 7, pp. 1-20.

